Electrical and Mechanical Safety in Repair, Maintenance, Alteration and Addition (RMAA) Works

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ABSTRACT

In Hong Kong, the repair, maintenance, alteration and addition (RMAA) sector becomes a more significant component of the construction industry with the implementation of the Mandatory Building Inspection Scheme (MBIS) by the Hong Kong SAR Government. Around 2,000 buildings would be targeted each year under the MBIS and it is expected that the volume of RMAA works will continue to increase. The public consultation paper issued by the then Housing, Planning and Lands Bureau (2006) indicates that the number of private buildings over 30 years' old in Hong Kong will rise to 22,000 by 2018. The condition of buildings becomes dilapidated as building age increases. Electrical and Mechanical (E&M) installations play an important role and involve a large number of practitioners. Among different types of accident, fall of persons from height and electrocution are the top two E&M works' killers. The safety of E&M work has not received sufficient attention. Only a very limited amount of safety research on E&M works especially in the RMAA sector has taken place. This study aims to reveal the causes of accidents on E&M works in the RMAA sector and provide recommendations to improve the safety and health of E&M practitioners. The significance of the study lies in providing a thorough E&M accident analysis in the RMAA sector, for the first time. A systematic approach with multidisciplinary inputs will lead to the identification of the causes of accidents and the formulation of holistic and practical measures for preventing accidents on E&M related RMAA works.

Keywords: Electrical and Mechanical; Safety; Construction Industry; Repair and Maintenance; Bayesian Network Approach

INTRODUCTION

Electrical and mechanical equipment (E&M) installations are one of the indispensable tasks within the range of Repair, Maintenance, Alteration and Addition (RMAA) works. E&M works involve a number of building services trades, when dealing with such as air-conditioning, fire services, plumbing, electrical wiring and lift installations. According to the Census and Statistics Department (2016), the number of persons directly engaged in “building services installation and maintenance activities” in 2015 was 71,357 and representing over 35% of the number of persons directly engaged in “all construction activities” (n=199,861). In terms of the number of “building services installation and maintenance activities” establishments, it was 6,820 and accounts for around 30% of the number of establishments of “all construction activities” (n=23,342). In view of the number of workers and companies involved, the E&M sector is being regarded as a significant sector in the construction industry.

The urban decay issue has become a hot issue in Hong Kong during the past decade. The condition of a building deteriorates as it ages, due to natural “wear and tear” and the lack of proper building repair and maintenance (Law, 2008). With reference to the statistics from the then Housing, Planning and Lands Bureau (2006), there were approximately 39,000 private buildings in Hong Kong in 2005, around 13,000 of which were aged over 30 years. That number will rise to 22,000 by 2018. According to the latest report published by HK2030 (HK2030, 2016), the ageing problem of Hong Kong’s building stock is predicted to intensify in the coming decades because of the boom of building construction in 1970-1980s. Private building units aged 70 years or above will be increased to 326,000 by 2046, which is about 300 times of housing stock of about 1,100 units in 2015. These old private units are concentrated in the old urban areas, for example, Yau Tsim Mong District with over 60,000 by 2046 (Figure 1).

The Hong Kong government has taken various initiatives to improve building safety. For example, the Mandatory Building Inspection Scheme (MBIS) has been launched in 2012, which requires all buildings aged 30 years or above to be inspected as well as followed by necessary repair and maintenance work (Buildings Department, 2012). Each year, 2,000 target buildings would be selected for inspection under MBIS. To support the MBIS, the government provides a Building Safety Loan Scheme (Buildings Department, 2013) to help building owners to finance repair, maintenance and upgrading works on fire services installations, lift installations, electrical installations and gas risers. With this government strategy, it is expected that the number of on-going E&M related RMAA projects will substantially increase in the coming years.

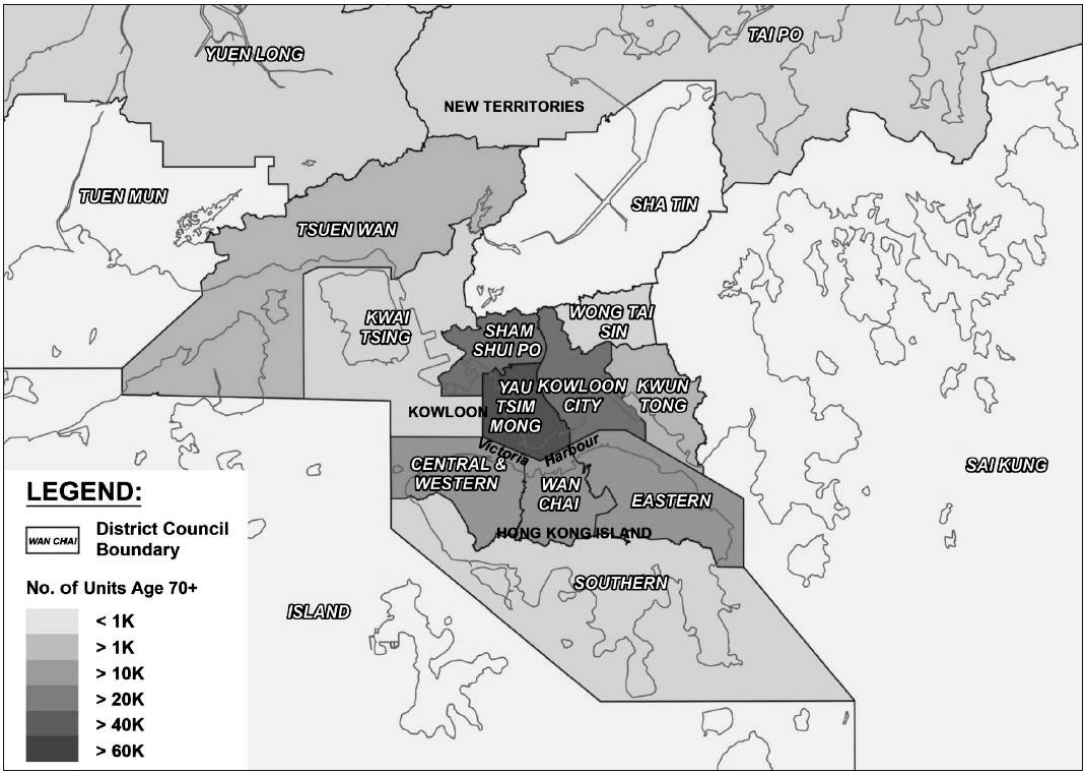

Figure 1. Private Housing Units Aged 70 or above by 2046 (by District Councils) (HK2030, 2016)

With this growing volume of E&M related RMAA works, it is predictable that the number of E&M accidents will also increase, which will not only cause project delays but also serious injuries and fatalities. A comprehensive research on E&M safety is vital to improve the safety performance of E&M works in RMAA. Despite the rising importance of this issue, there is limited study on E&M safety of RMAA works.

This research study aims to reveal the causes of accidents on E&M works in the RMAA sector with a Bayesian network approach and provide recommendations to improve the safety and health of E&M practitioners. The research will focus on the two major types of accidents, fall of person from height and electrocution. Among various safety analysis of accident causes, Bayesian network (BN) analysis is becoming a popular technique as it considers dependencies among variables to establish cause-effect relationships with a directed acyclic graph (DAG). This method is powerful to reveal complex cause-effect relationships and develop model for accidents prediction. In this study, accident cases collected from the Coroner's Court and the Electrical and Mechanical Services Department (EMSD) will be first analysed to preliminary identify the cause factors of E&M accidents. Focus group meetings with E&M works' practitioners and safety experts will identify values for the variables and indicate the direction of each pair of variables. Structured interviews will solicit views of different stakeholders to fine tune the BN model. In the last stage, a

questionnaire survey will be conducted to collect more quantitative data for parameter estimation of the BN model.

RESEARCH AIM AND OBJECTIVES

Common E&M accidents include fall from height and electrocution, which are the top two killers on repair, maintenance, alteration and addition works in Hong Kong. The research study aims to reveal the causes of E&M works accidents with a Bayesian network approach and provide a series of recommendations to enhance the safety and health of E&M practitioners on RMAA works, particularly for those two types of accident.

Objectives of the study

1. To provide a critical review of the current E&M installation safety standards and safety performance on RMAA works.

2. To identify the causes of E&M accidents on RMAA works with a Bayesian network approach.

3. To identify effective measures to be implemented in order to reduce E&M accidents on RMAA works.

4. To give practical recommendations to various stakeholders on how to enhance E&M installation safety in the RMAA sector.

SIGNIFICANCE AND VALUE OF RESEARCH

Hong Kong, a highly developed and densely populated city with a very large number of ageing buildings. To maintain Hong Kong's ageing building stock appropriately and uphold public safety in a sustainable manner, it is vital to inspect and repair these buildings regularly. E&M installations represent a substantial proportion of all works in the RMAA sector. As repair and maintenance of air conditioning systems and water pipes always involve working at height, fall injuries frequently occur when using ladders. Most injured workers are unskilled labourers working on a temporary basis. For E&M works, the key hazards are being identified in activities that involve working at height, with electricity, in confined working spaces, lifting, machinery (for lift and escalator), welding, using handheld tools, etc. Some hazards in E&M works are quite particular, such as the E&M work processes in lifting of chillers and generators, electrical hazards at switch gear works, and confined space hazards around water tanks, etc.

Most air-conditioning and plumbing maintenance involves working at height outside the building. E&M fire services maintenance workers may have to work at a false ceiling level with a large ceiling void but no proper working platform. Lift maintenance works are complex and involve

different processes such as lift pit working and lift machine room working that increase the likelihood of lift related accidents, because the spaces are particularly confined and complex. Wong, et al (2005) pointed out that the four factors: inappropriate equipment, lack of design for safety, lack of resources and insufficient housekeeping are the main factors contributing to fall injuries. Analysis of twenty-two case studies in Chan et al. (2007) revealed that falls from bamboo scaffolding were the most common accidents in the case of residential building repair and maintenance. In addition to fall accidents, electrocution is also a major type of E&M related accident.

A full investigation into the major causes of E&M accidents and corresponding improvement measures is urgently needed to formulate effective strategies to prevent related accidents in RMAA works. Currently, the research on E&M installation, especially for RMAA works, is tremendously limited. This research is essential to fill the research gap. Most of the existing studies used conventional descriptive statistics, such as factor analysis, analysis of variance, multiple regression, etc., to investigate the accident factors. An accident is often the combined outcome of a number of factors. These methods have inadequate ability in revealing complex cause-effect relationships and constructing model for predicting accidents (Martin et al., 2009 and Leu and Chang, 2013). Bayesian network (BN) is one of the recognized approaches to consider dependencies among variables to determine cause-effect relationships. In view of this, a BN approach will be adopted in this study to investigate E&M accidents in the RMAA sector.

It is anticipated that the study will provide insights into the root causes of both non-fatal and fatal E&M accidents and recommend a series of holistic and practical strategies to reduce them. It is expected to lead to an obvious reduction in fatalities and injuries in the RMAA sector. This contribution is not only beneficial to E&M workers themselves but also to the industry and the community.

BAYESIAN NETWORK APPROACH

Bayesian network (BN) approach has been adopted in accident analysis of different industry contexts. For example, Trucco et al. (2008) conducted a BN model to investigate organizational factors in risk analysis with a case study of maritime transport system. Zhao et al. (2012) analysed major factors related to hazardous material transportation accidents with BN approach. Regarding accident analysis in the construction industry, Zhou, et al. (2008) established a BN model to identify strategies for the improvement of human safety behavior by considering safety climate and personal experience. Martin et al. (2009) analysed fall from height accidents in the construction industry of Spain with BN. Nguyen, et al. (2016) demonstrated using BN to predict safety risk of working at heights in construction works. Leu and Chang (2013) and Zhou, et al. (2011)

developed a BN-based safety risk assessment model for steel construction projects and deep foundation pit construction project respectively.

BN has demonstrated to be a powerful approach for accident analysis in complex socio-technical environments. It is a useful knowledge representation and reasoning tool which establishes complex dynamic model to visualize the probabilities interrelationships among a large number of independent and dependent variables (Heckerman, 1997; Tran , 2013 and Hanninen, 2014). It helps to identify the most significant causes of accidents. It has been extensively used to develop decision-support systems.

RESEARCH METHOD

This study will adopt a hybrid form of BN model construction, with expert knowledge to construct a prior BN structure and following by learning the parameters of the BN from questionnaire survey data. (Kjaerulff and Madsen, 2008; Zhao et al., 2012) The whole research process comprises: (1) updating the literature review; (2) case studies; (3) focus group meetings; (4) structured face-to-face interviews; (5) empirical questionnaire survey; (6) data analysis; and (7) validation of the results.

Literature review

The research will begin by conducting an extensive literature review of safety research on E&M works in the RMAA sector from textbooks, professional journals, conference proceedings, refereed publications, research monographs, workshop seminars, and internet materials across different countries including the United Kingdom, Australia and Hong Kong. An overview and analysis of applying Bayesian network approach in construction safety research will be conducted. Hong Kong accident statistics data will be obtained from relevant government departments (including the Labour Department, Electrical and Mechanical Services Department, Architectural Services Department, and Census and Statistics Department, etc.) and the patterns, nature and volume of E&M accidents related to repair and maintenance work examined and categorised. The review will facilitate the identification of factors leading to accidents of E&M works in RMAA projects as the variables for BN model construction. Besides, good E&M works practices in the RMAA sector will also be identified.

Case studies

Both fatal and non-fatal E&M accidents will be collected for analysis in this study. Information on fatal and non-fatal cases will be obtained from the Labour Department and the Electrical and Mechanical Services Department, further supplemented by the “WiseNews”, an electronic database containing local newspaper archives (Hon and Chan, 2013).

Accident cases collected from different sources will be triangulated to ensure accuracy and reliability of the raw data.

Cases files obtained from the Coroner's Court are another source of information for this research. The Coroner's Court has the power to inquire into the causes and circumstances of certain deaths. With the consent of the Coroner's Court, cases files of E&M fatalities in RMAA sector in the past 15 years will be examined. The files include information on police investigation files, death investigation reports, fatal accident reports by the Labour Department of the Hong Kong Government, autopsy reports and medical reports. The advantages of referring to the coroner's reports are that the data is highly reliable and strictly validated by police investigation of the circumstances and causes of accident (Gephart, 1993 and Goh et al., 2012). The purpose of case studies is to identify immediate factors and contributing factors of E&M accidents in RMAA projects. These factors will then become the variables of BN structure.

Focus Group Meetings

Focus group meetings will be arranged with safety experts and E&M works practitioners to gather expert knowledge on E&M safety of RMAA projects. It is an effective and convenient way to collect a large amount of information supplementing the traditional individual interview because the meeting itself generates synergism and stimulation among participants (Haslam, 2003 and Vaughn et al., 1996). The primary purpose of the focus group meetings is to gather expert knowledge for construction of the BN model structure. During the focus group meeting, the experts will be presented with the factors identified from literature review and case studies. They are required to indicate the interrelationships direction of the factors and base on their expert knowledge to preliminarily set values for the variables to construct a BN model. Based on the results of focus group meeting, a directed acyclic graph which presents the factors related to E&M works safety will be constructed.

Structured interviews

After preliminary developing the BN model structure from expert knowledge of the focus group meetings, about 20 structured interviews will be conducted with E&M practitioners of five key E&M installation trades, including air-conditioning, fire services, plumbing, lift installations and electrical works to fine tune and ensure that the BN model is realistic and applicable across the board to major trades of E&M works and at the same time reflects the unique characteristic in RMAA projects.

Questionnaire Survey

A questionnaire survey will be conducted to collect quantitative data for parameter estimation of the BN model. Expectation-maximization (E-M)

algorithm (Zhao et al., 2012) will be implemented using the software Netica (Norsys Software Corporation). Respondents will be required to rate and prioritize the causes of E&M accidents and measures for improving safety. A list of E&M accident causes and possible recommendations on E&M's RMAA works which has been consolidated previously will be reviewed and further modified. E&M frontline workers in the RMAA sector and RMAA contractors will be invited to participate in the survey.

PRELIMINARY RESEARCH FINDINGS

Based on the preliminary findings from literature review, air-conditioning installation is the most common trade leading to fatality among various E&M trades. According to the Labour Department (2016), there were at least seven E&M works related fatal cases occurred in 2016 (Table 1). Six out of seven fatal cases were occurred in RMAA works which far outweighed that of new construction works. It clearly reflected that the safety problem of E&M works in RMAA sector is significant. Among different types of accidents, fall of person from height and electrocution are regarded as the top two killers of E&M works.

Table 1. Fatal accident of E&M RMAA work in 2016, Labour Department (2016)

Date of accident	Trades	Type of works	Accident
January 2016	Air-conditioning	RMAA works	A worker fell from about 3m through the false ceiling onto the ground while replacing the air duct insulation material of an air-conditioning system.
February 2016	Lift	New works	A worker was struck to death by the descending counterweight of a lift while working at the lift pit.
April 2016	Air-conditioning	RMAA works	A worker fell from about 4m above ground while carrying out air-conditioning work inside a plant room of a building.
May 2016	Electrical wiring	RMAA works	A worker electrocuted while removing an electrical installation of a building.
June 2016	Plumbing & Drainage	RMAA works	A worker fell about 2.6m from a wooden A-ladder while installing water pipes near the ceiling of a shop unit.
August 2016	Electrical wiring	RMAA works	A worker received an electric shock while carrying out electric cable laying work inside the false ceiling of a building.

November 2016	Air-conditioning	RMAA works	A worker fell from an aluminium folding ladder to the ground while inspecting an air-conditioning unit that was suspended from the ceiling.

CONCLUSIONS

Electrical and Mechanical (E&M) installation was identified as one of the most hazardous trades in the construction industry worldwide. Some trade unions and contractor associations of E&M works has expressed serious concerns for safety of their member practitioners in different occasions, especially in RMAA works. E&M installations involve a considerable proportion of workers in the construction industry. A safe E&M work is essential to the success of any construction projects. This research project provides an overview of E&M works related accidents in the RMAA sector, identify major factors leading to E&M works related accidents and formulate a series of safety measures through a series of research tools including focus group meetings, cases studies, structured interviews, and questionnaire survey. Bayesian network analysis will be adopted as a powerful approach for accident analysis to identify the most significant causes of accidents and supports decision making. It is expected that the research project will provide some insight into the practical and innovative ways to reduce the number of E&M related accidents in RMAA works. The research also facilitates productive discussions and engender innovative initiatives on this crucial subject of the industry and brings tremendous value in better safeguarding E&M workers' health and safety.

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